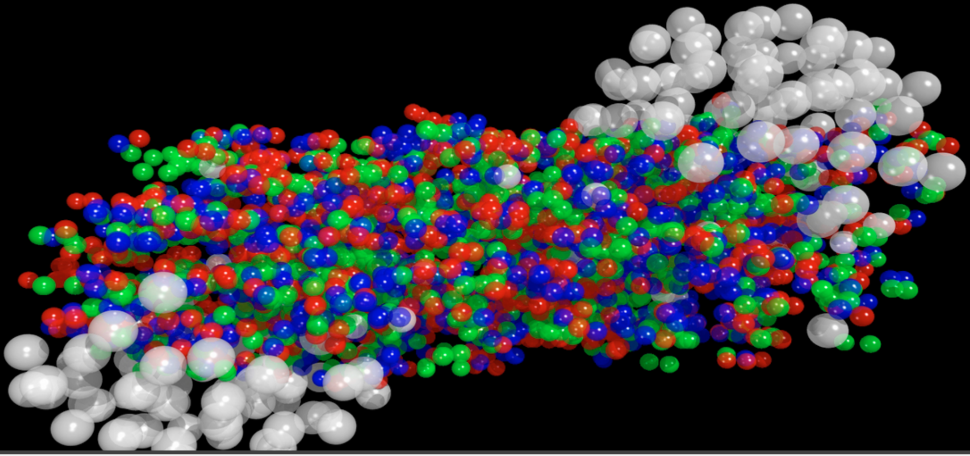
Detecting rare phenomena at high rates with Compressed Baryonic Matter experiment

Maksym Teklishyn
for the CBM Collaboration

GSI (Darmstadt),

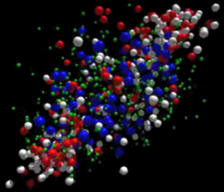
June 11, 2024

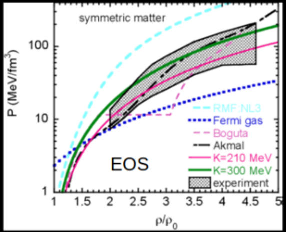
Seminar at CP3, UCLouvain

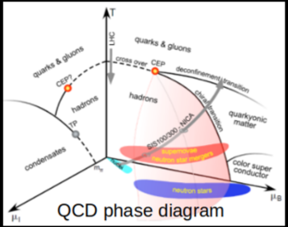


Introducion to heavy ions

Nuclear mater at neutron star density

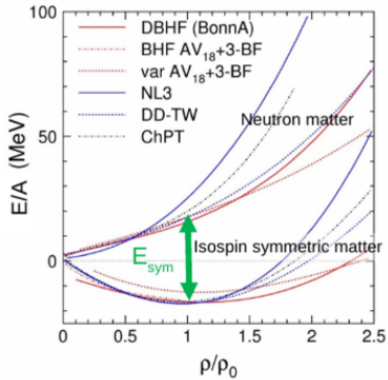






Equation of state of nuclear mater

$P = \rho^2 \delta(E/A)/\delta\rho$ T=const



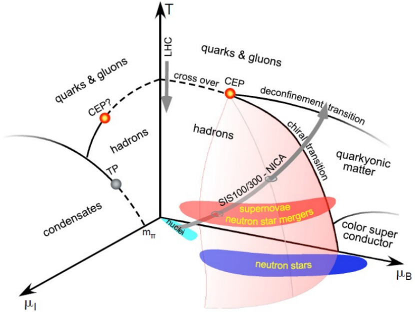
Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5

$$E_A(\rho,\delta) = E_A(\rho,0) + E_{\text{sym}}(\rho)\cdot\delta^2 \quad \text{with} \quad \delta = \frac{\rho_n - \rho_p}{\rho}$$

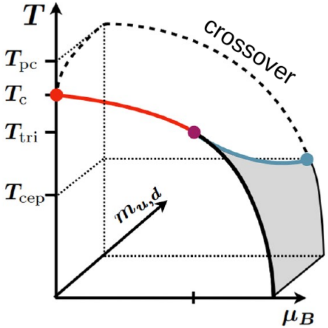
- **Symmetric matter ($\delta = 0$):**
  - $E/A(\rho_0) = -16$ MeV
  - slope $\delta(E/A)(\rho_0)/\delta\rho = 0$
  - curvature $K_{nm} = 9\rho_0^2\delta^2(E/A)/\delta\rho^2$
  - $K_{nm}(\rho_0) = 210 - 220$ MeV (Giant monopole resonances)
- **Symmetry energy:**
  - $E_{\text{sym}}(\rho) = E_{\text{sym}}(\rho_0) + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{\text{sym}}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2$
  - Empirical value $E_{\text{sym}}(\rho_0) \approx 30$ MeV
  - Theoretical value $L(\rho_0) \approx 60$ MeV

Exploration of the QCD phase diagram

State of the nuclear matter depending on baryochemical potential (μ_B), isospin symmetry (μ_I) and temperature (T)



lQCD, F. Karsch, arXiv:1905.03936



$T_{pc} = 156.5 \pm 1.5\,\text{MeV}$ at $\mu_B = 0$

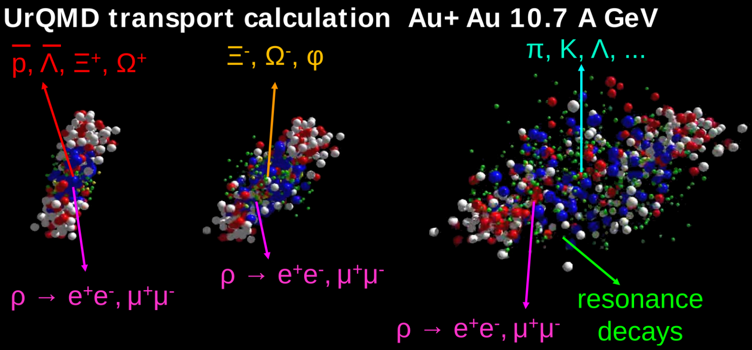
$T_{\text{cep}} < T_c^0 = 132^{+3}_{-6}\,\text{MeV}$ (chiral limit)

Special interest: observation of the phase transition and finding the critical point

Heavy ion collisions

Ultra-relativistic Quantum Molecular Dynamics (UrQMD)

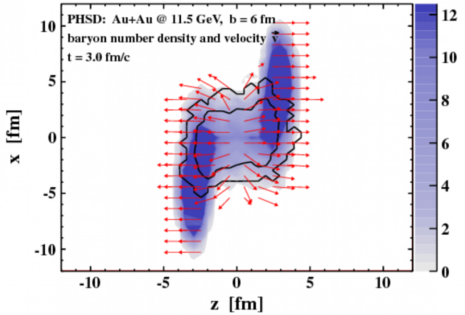
- Combines with hydrodynamic models for comprehensive simulations.
- Initial dense phase: hydrodynamic treatment.
- Later dilute phase: microscopic transport.

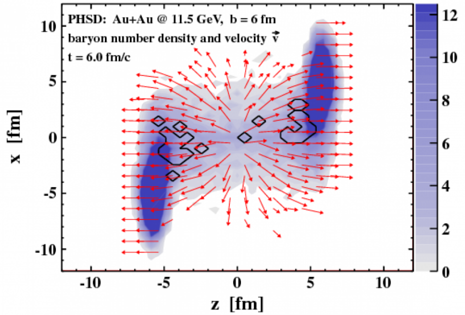


Heavy ion collisions

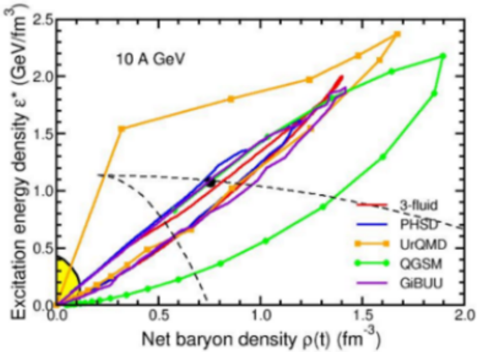
Parton-Hadron-String Dynamics (PHSD)

- Microscopic off-shell transport approach for relativistic heavy-ion collisions.
- Describes the evolution from initial scatterings through QGP to hadronization and hadronic phase.
- Developed by Giessen/Frankfurt groups based on Hadron-String Dynamics (HSD).





Heavy ion collision time evolution

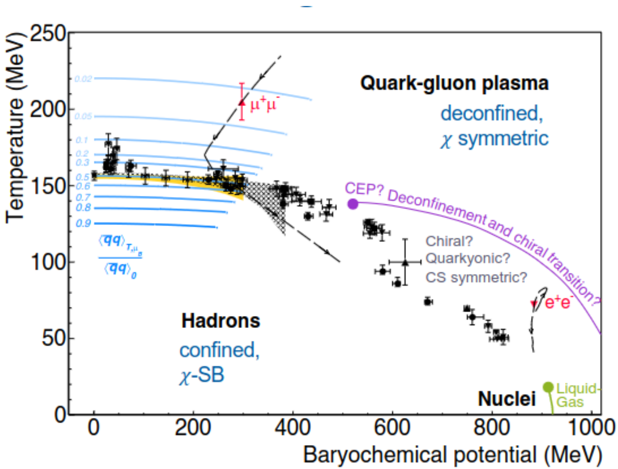


- Clockwise evolution, 1 step is 1 fm/c
- Excitation energy density:s energy density minus mass density
- Dashed line: possible area of phase coexistence

Exploration of the QCD phase diagram at high baryonic densities:

- Fixed-target experiment
- Investigation of the properties of dense QCD matter
- Transport calculations at SIS100 energies:
  - $\epsilon \leq 2.5\,\text{GeV fm}^{-3}$ and $5 \ldots 8\rho_0$, expecting to reach neutron-star densities
- Long time ($\geq 5\,\text{fm/c}$) in dense QCD regime

Searching for landmarks of the QCD matter phase diagram



T. Galatyuk CPOD 2024

Experimental challenges:

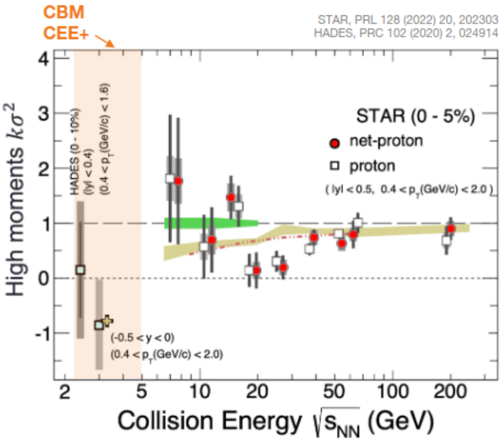
- Isolate unambiguous signals of new phases of QCD matter, order of phase transitions, conjectured QCD critical point
- Probe microscopic matter properties

Measure with utmost precision:

- Light flavour (chemistry, vorticity, flow)
- Event-by-event fluctuations (criticality)
- Dileptons (emissivity)
- Charm (transport properties)
- Hypernuclei (interaction)

Almost unexplored (not accessible) so far in the high μ_B region

Critical Point Search

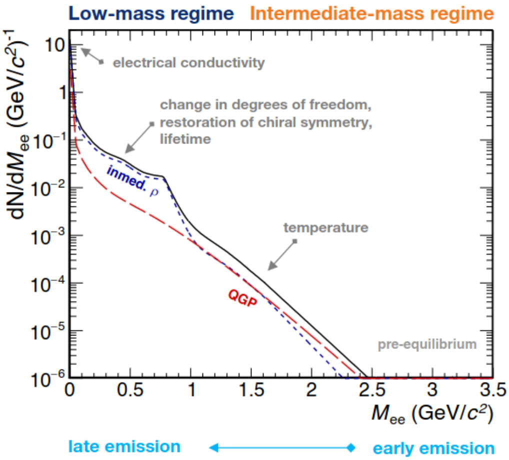


$$\kappa_n(N_q)\frac{N_q}{VT^3} = \frac{1}{VT^3}\frac{\partial^n \ln Z(V,T,\mu)}{\partial(\mu_q/T)^n} = \frac{\partial^n p}{\partial \mu_q^n} = \chi_n^q$$

Non-monotonic trend of the higher moments k_4/k_2 of net-proton number distributions, visible in a beam energy scan?

- Current data consistent with non-critical physics? $\rightarrow$ reduced errors to come from STAR BES-II
- Sensitivity to features of the QCD phase diagram grows with the order of the moment
- Higher order moments probe the tails – statistics/artefacts!

Thermal Dilepton Measurements

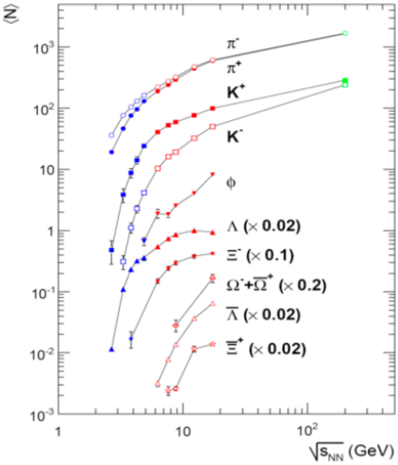


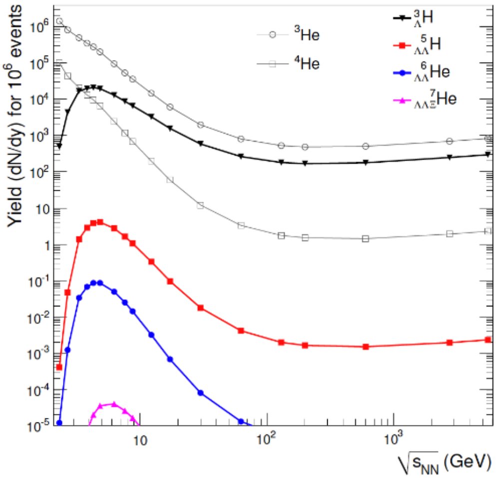
- **Dileptons are rare probes**
- **Decisive parameters for data quality:**
  - Interaction rates (*IR*) and signal-to-combinatorial background ratio (*S*/*CB*): effective signal size: $S_{\text{eff}} \sim IR \times S/CB$
- Needs coverage of mid-rapidity, low-$M_{\ell\ell}$, and low-p
- Isolation of thermal radiation by subtraction of measured decay cocktail $(\pi^0, \eta, \omega, \phi)$, Drell-Yan, $c\bar{c}$ $(b\bar{b})$
- **Temperature sensitive to phase transition**

Seck, MSc 2015

Particle multiplicities

Blume 2005, Adronic 2010

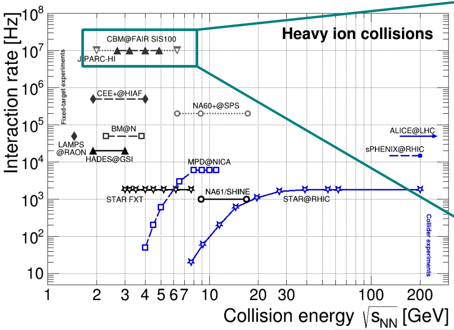


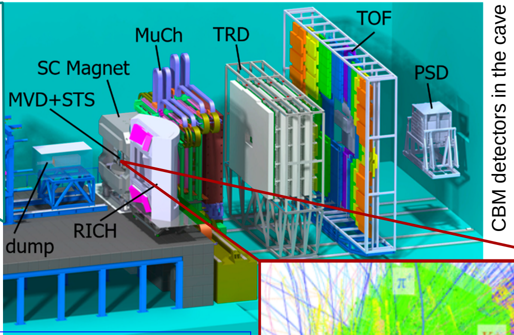


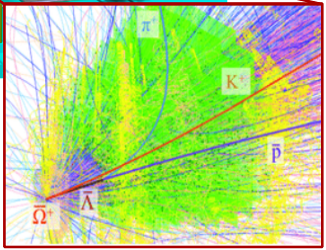
CBM experiment

N. Herrmann EPJ Web Conf. 259 (2022)

detection of the rare probes of compressed nuclear matter in high-rate heavy-ion collisions





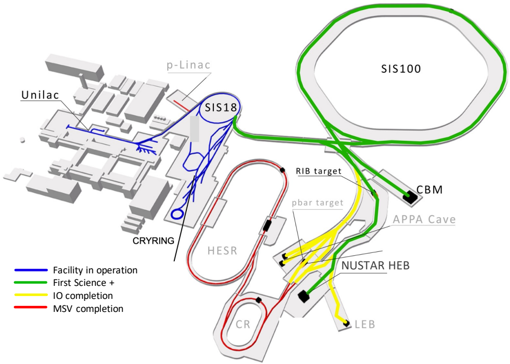


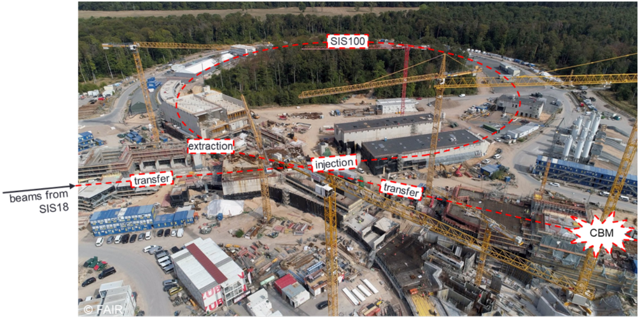
T. Galatyuk, NPA 982 (2019), update 2022

- CBM aims for precision measurement of rare and penetrating probes
- Unprecedented beam-target interaction up to $10\,\mathrm{MHz}$
- Challenges for detectors:
  - hundreds tracks in aperture /interaction, high occupancy
  - low momenta → low material budget

Facility, accelerator, and infrastructure

Facility for Antiproton and Ion Research: exploring new frontier



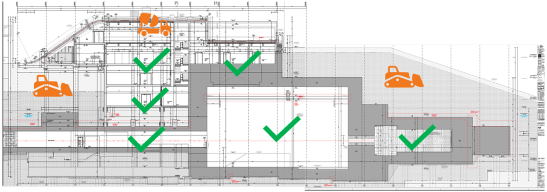


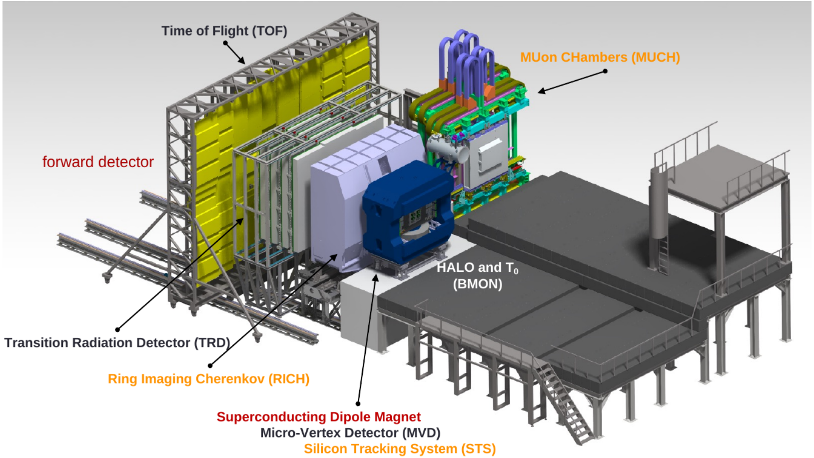
- Located in Darmstadt, Germany, FAIR is one of the largest projects for basic research in physics worldwide.
- The facility will provide particle beams with unprecedented intensity and quality.
- Research at FAIR will cover areas such as nuclear structure, nuclear astrophysics, hadron physics, and atomic physics.
- International collaboration with scientists from more than 50 countries.

Compressed Baryonic Matter experiment

- Heavy-ion experiment, first at the beam line: CBM
  - CBM stands for Compressed Baryonic Matter
  - It is designed to explore the properties of nuclear matter at high densities.
  - The experiment aims to study the behavior of matter under extreme conditions, similar to those in neutron stars
- Relativistic heavy-ion beams: gold up to $11\,A$GeV, lighter ions up to $14\,A$GeV
  - gold ions are used because they provide a large number of nucleons for collision experiments
  - lighter ions provide complementary information
- Beam intensity up to 10^9 ions/s
  - high beam intensity allows for the exploration of rare processes







Experimental complex and infrastructure: cave, magnet, mechanics

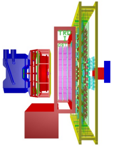
Tracking and vertexing: Silicon Tracking System and Micro-Vertex Detector

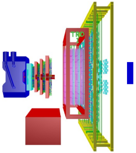
Event geometry determination: forward detector

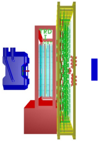
Global tracking and particle identification: RICH, TRD, ToF, MUCH

CBM detector configurations

Setup	Included detectors	Average “Day-1” interaction rate	Average MSV - interaction rate
ELEHAD	MVD,STS,RICH,TRD,TOF,PSD	0.1 MHz	0.1 MHz
MUON	STS,MUCH,TRD,TOF,PSD	1 MHz	5 MHz
HADR	STS,TRD,TOF,PSD	0.5 MHz	5 MHz


ELEHAD


MUON


HADR

- **CBM setup** can be rearranged depending on the goals

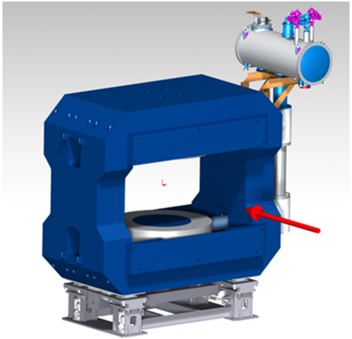
  ELEHAD precise tracking and vertexing, enhanced e/π separation
  MUON best muon PID
  HADR ultimate rates for rare hadrons

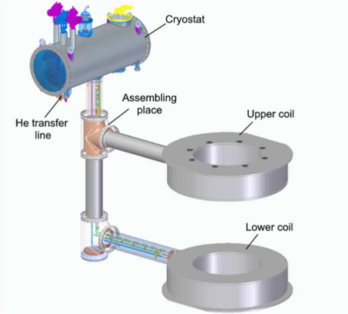
CBM cave

- CBM cave will host HADES and CBM experiments
  - 1 Tm superconductive dipole for CBM
- Power electronics under the concrete platform
- Iron beam dump at the back wall

Cave is being prepared, crane installed

Superconductive dipole magnet





- The H-type superconducting magnet
- Vertical magnetic field 1 Tm
- Depth of 1 m from the target

- New magnet gap requested by STS:

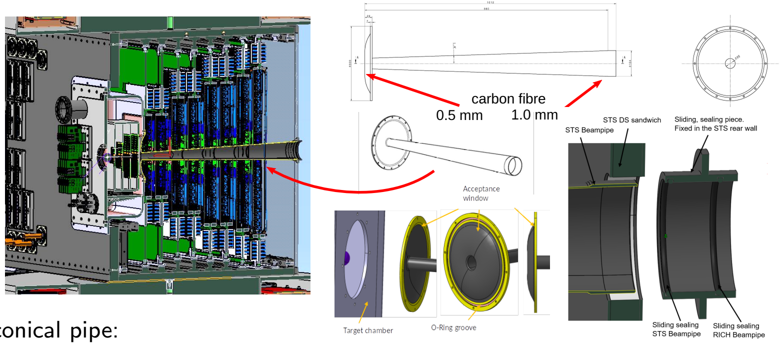
width	330 cm (+30 cm)
weight	147 cm (+3 cm)

- Assigned for European manufacturer after terminated cooperation with Russian institutions

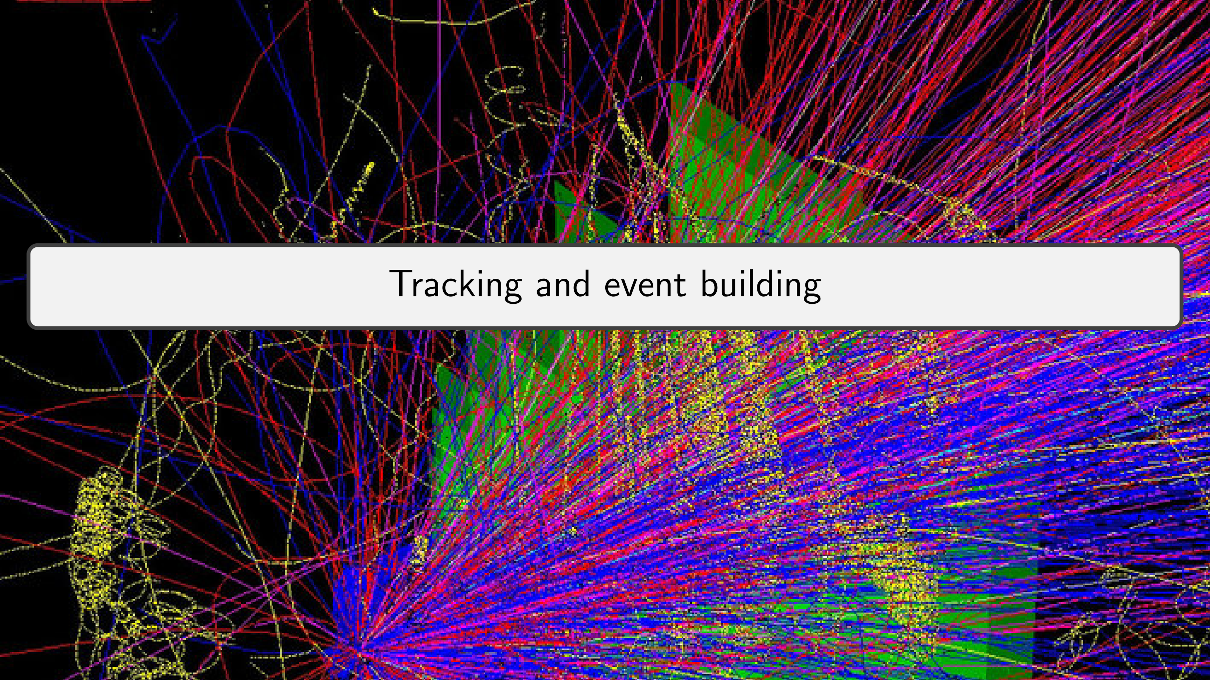
Carbon-fibre beam pipe

pushing the limits of vacuum technique

- Beam pipe full-size prototype will be produced this year
- FEM simulation: critical part is transition from membrane to cone



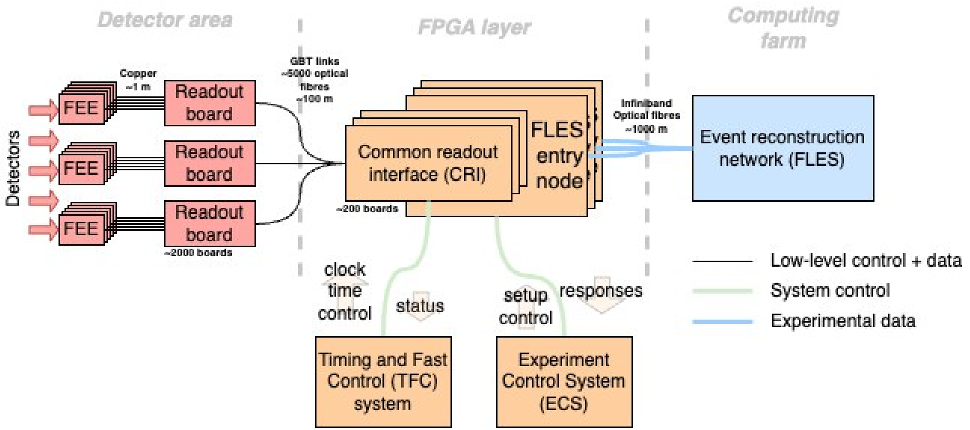
- Window and conical pipe:
  - separate target/MVD vacuum and non-interacting beam from STS aperture
- Carbon fiber material: 0.5 mm (window) 1.0 mm (1.8° cone)
- Zero-force interface at back wall towards downstream section



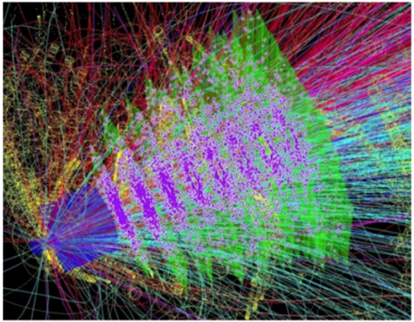
Tracking and event building

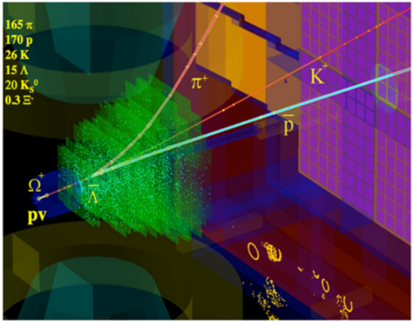
CBM DAQ chain

- CBM read-out operates with continuous beam in free-streaming mode
- Full online event processing



Challenging reconstruction and tracking environment



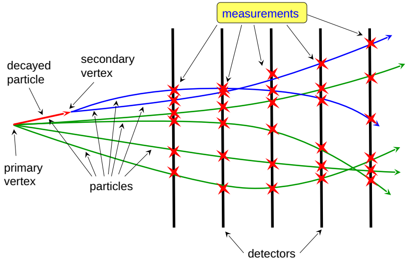


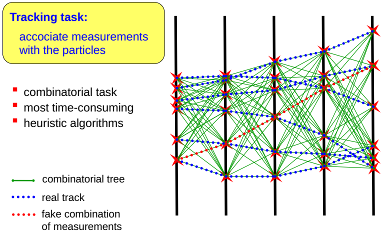
- $\lesssim 700$ charge particle tracks in the detector per $11\,A\mathrm{GeV}$ Au-Au collision
- Continuous beam, free-streaming detector operation
- Complex signatures of cascade decays to be found

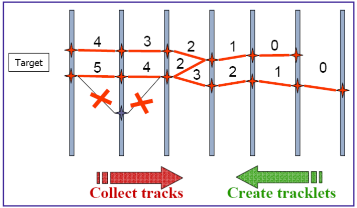
  Ω decay examples: $\Omega^+ \to \bar{\Lambda}(\to \pi^+\bar{p})K^+,$

  $\Omega^+ \to \bar{\Xi}^0(\to \pi^+\bar{\Lambda})\pi^+ \ldots$
- On-line event reconstruction and selection: data being fed non-stop to the computing farm

Tracking task: consequences for the tracker design



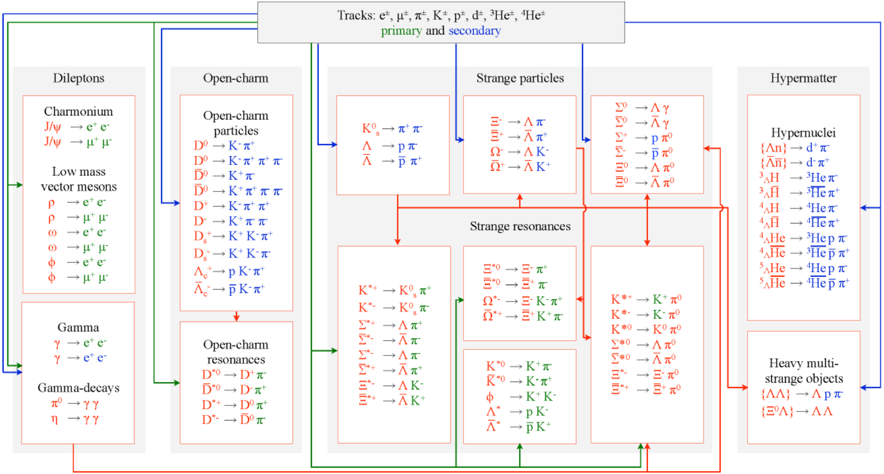




- Challenging track reconstruction in dense environment
  - high granularity, timing information
  - robust algorithms, online reconstruction
- Complex decay chains withing the tracker
- Light detector ⇎ fast read-out

On-line reconstruction algorithms for the CBM and ALICE experiments, S. Gorbunov

KF Particle Finder



PhD thesis Maksym Zyzak

Momentum resolution of the tracker

Z. Drasal, W. Riegler DOI:10.1016/j.nima.2018.08.078

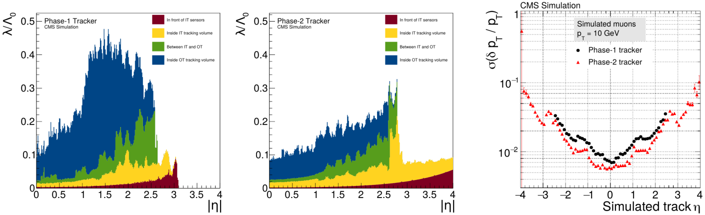
Momentum measurement precision:

$$\left.\frac{\delta p}{p}\right|_{\text{res.}} = \frac{\sigma p}{0.3BL^2}\sqrt{\frac{720N}{(N-1)(N+1)(N+2)(N+3)}},$$

$$\left.\frac{\delta p}{p}\right|_{\text{scat.}} = \frac{N}{\sqrt{(N+1)(N-1)}} \cdot \frac{0.0136\ \text{GeV/c}}{0.3\beta BL} \cdot \sqrt{\frac{\lambda}{\Lambda_0}} \cdot \left(1 + 0.038 \ln \frac{d}{\Lambda_0}\right),$$

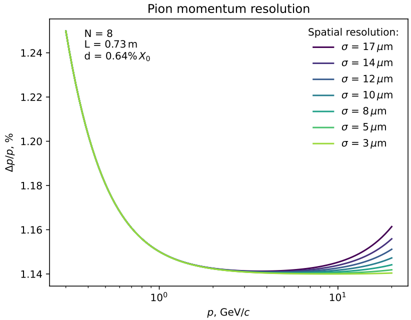
where $\beta = \sqrt{p^2/(p^2+m^2)}$

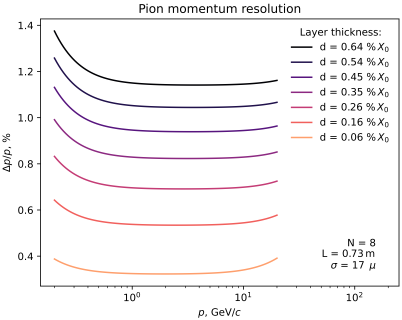
Example of the CMS Tracker Upgrade:



CBM Tracker momentum resolution

- Limited benefit from better resolution
- Huge improvement with reduced material (integration?)



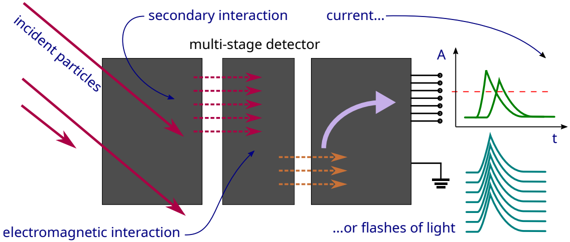


- Enormous challenge for mechanics. r/o, cooling for
  - $\mathcal{O}(1\,\mathrm{m}^2)$ layer surface
  - $\mathcal{O}(1‰)$ layer thickness

CBM Detector construction

What is a particle detector

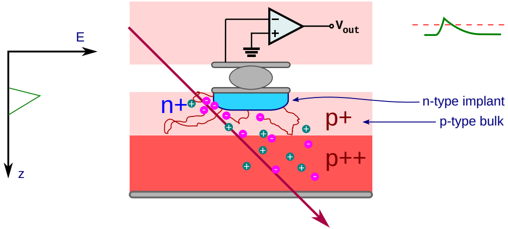
- Device that makes microscopic particles being observed
  - visual observation (bubble chambers, spark chambers, emulsion films)
  - pulses of current to be read out (most of modern detectors)



- Event $\Longrightarrow$ current/light (with its characteristics), no event $\not\Longrightarrow$
- Real detectors are complex, multi-stage devices, they feature:
  - always **electromagnetic interaction** (at some stage)
  - often **electrical charge deposition** and transport

How to make a hybrid pixel

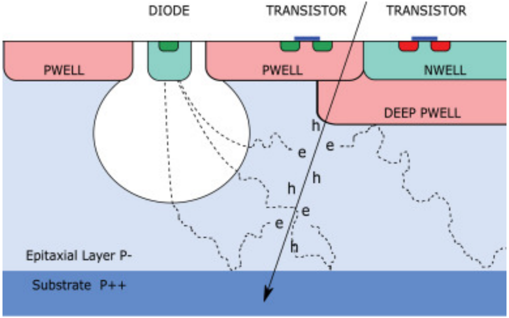
1. Take a silicon diode
2. Do few modifications as we will collect charge carriers using diffusion:
   - invert type to collect electrons in diode field
   - make it thinner, add low-ohmic p-substrate
   - smaller implant for lower capacitance

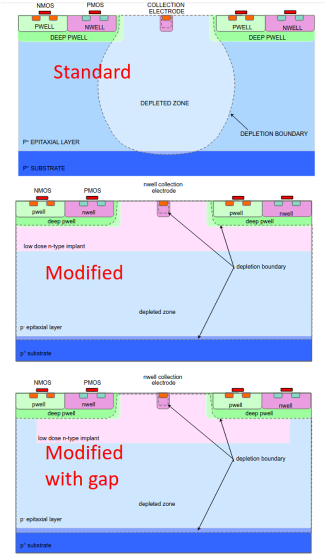


3. Add r/o electronics...

Monolithic Active Pixel Sensors (MAPS)

- R/o electronics integrated in the same chip
  - P/NWELLs needed for transistors
  - analogue and digital circuits on the same crystal





- Low material budget, easier integration
- Pixel size of $\mathcal{O}(10 \times 10\,\mu\mathrm{m}^2)$

MIMOSIS requirements from MVD

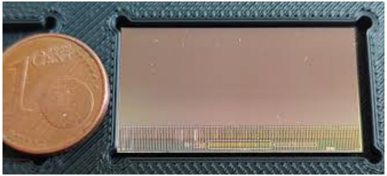
- Based on ALPIDE architecture
- Discriminator on $27 \times 30\,\mu\mathrm{m}^2$ pixel
- Multiple data concentration steps
- 8 x $320\,\mathrm{Mbps}$ links (switchable)

Specifications

- Technology: TowerJazz $180\,\mathrm{nm}$
- Epi layer: $\simeq 25\,\mu\mathrm{m}$
- Epi layer resistivity: $> 1\,\mathrm{k}\Omega\mathrm{cm}$
- Sensor thickness: $60\,\mu\mathrm{m}$
- Pixel size: $26.88\,\mu\mathrm{m} \times 30.24\,\mu\mathrm{m}$
- Matrix size: $1024 \times 504\,(510696\,\mathrm{pix})$
- Matrix area: $\simeq 4.2\,\mathrm{cm}^2$
- Matrix readout time: $\simeq 5\,\mu\mathrm{s}$ (event driven)

Requirements

- Spatial resolution: $\simeq 5\,\mu\mathrm{m}$
- Time resolution: $\simeq 5\,\mu\mathrm{s}$
- Material budget: $0.05\%\ X_0$
- Power consumption: $< 100 - 200\,\mathrm{mW/cm}^2$
- Operation temperature: $-40\,^\circ\mathrm{C}$ to $30\,^\circ\mathrm{C}$
- Temp gradient on sensor: $< 5\,\mathrm{K}$
- Data flow (peak hit rate): $@7 \times 10^5\,/(\mathrm{mm}^2\,\mathrm{s})$ $> 2\,\mathrm{Gbit/s}$



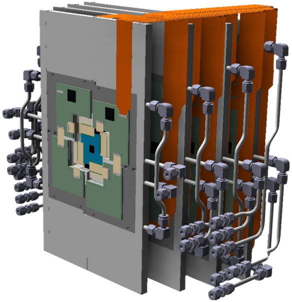
MVD: ultra-light detector for precise vertex determination

Micro Vertex Detector (MVD) for the CBM experiment at GSI/FAIR:

- Secondary vertex determination ($\simeq 50\,\mu\mathrm{m}$), background rejection in di-electron spectroscopy, reconstruction of weak decays
- Vacuum/magnetic field operation
- 4 stations
- $\simeq 300$ CMOS sensors
- Radiation tol* (non-ion): $> 7 \times 10^{13}\,\mathrm{neq/cm^2}$
- Radiation tol* (ionizing): $\simeq 5\,\mathrm{Mrad}$
- Power consumption: $40 - 70\,\mathrm{mW/cm^2}$

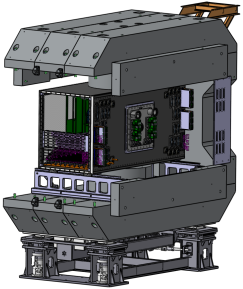
Quadrant (smallest functional unit):

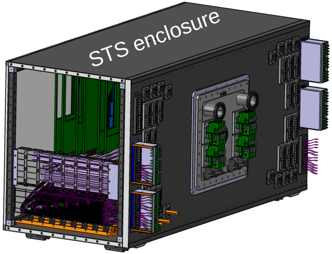
- CVD Diamond / TPG carrier for heat evacuation
- CMOS pixel sensors: $\simeq 5\mu s$ read-out
- Aluminum heat-sink (actively cooled)



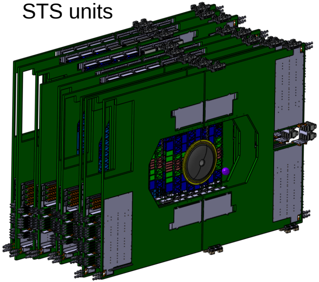
Design and geometry of the Silicon Tracking System

Detector inside the CBM magnet

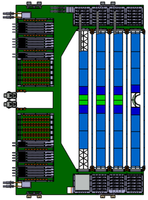


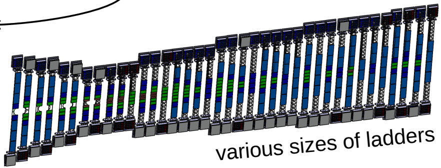


STS units



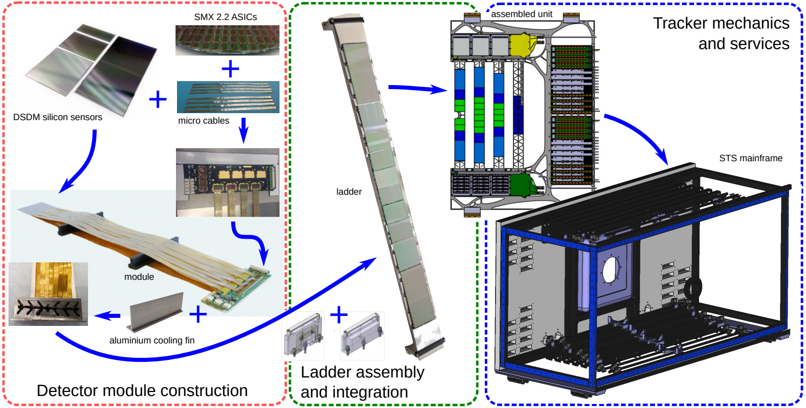
half-Unit: ladders on a C-frame





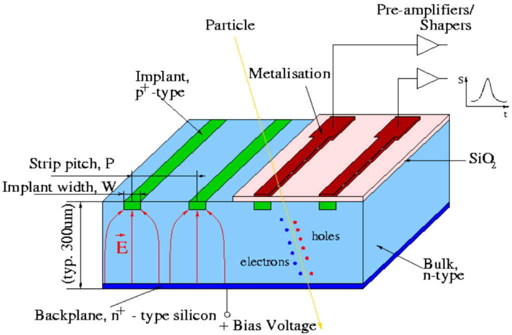
Components:
- 8 stations
- 18 half-units
- 106 ladders
- 876 modules

Silicon Tracking System assemble



- 876 modules, 106 ladders, $\gtrsim 14\,000$ r/o ASICs, $\gtrsim 7\,000$ LDOs
- Large number of **unique components**: 199 module variants, 38 ladder types
- Modular design (3+5 mechanically independent stations) introduced M. Teklishyn - VCI 2022

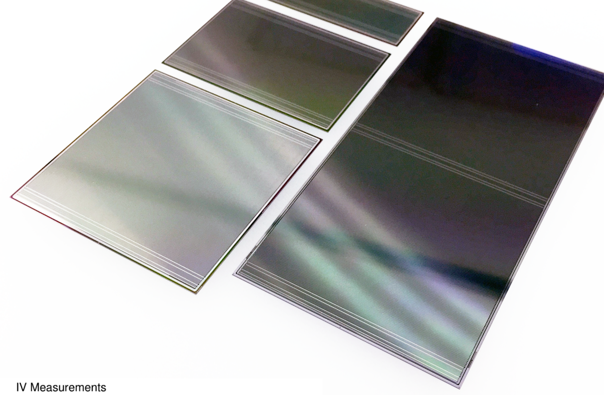
Micro-strip sensor and how it works

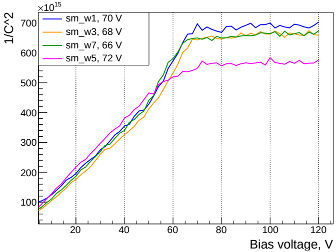


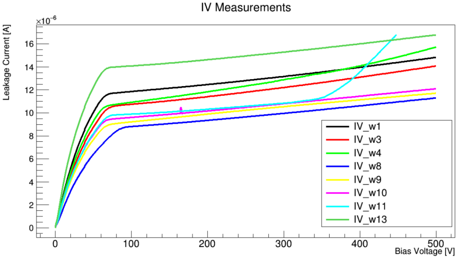
Particle looses energy $\xrightarrow{\text{converts to charge}}$ e-h pairs drift towards electrodes in $\vec{E}$ $\xrightarrow{\text{current is induced}}$ CSA integrates current $\longrightarrow$ amplification $\longrightarrow$ digitisation

DSDM silicon micro-strip sensors

- Double sided n-type silicon sensors (XY positioning): 1024 strips each side, p-side tilted by 7.5° to the edge
- **Thickness** $320\,\mu m \pm 15\,\mu m$
- **Pitch size** $58\,\mu m$ for both sides
- 62 mm $\times$ 22 mm, 42 mm, 62 mm or 124 mm
- Strip coupling capacitance (n) $14.1 \pm 0.1\,\mathrm{pF/cm}$ interstrip capacitance $0.37 \pm 0.01\,\mathrm{pF/cm}$

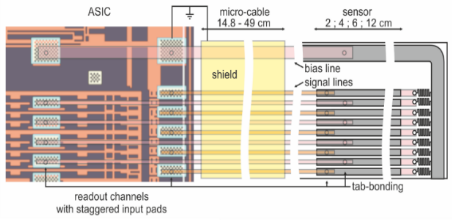




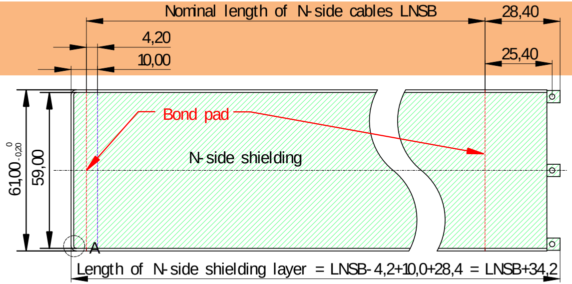


Ultra-thin r/o micro cables

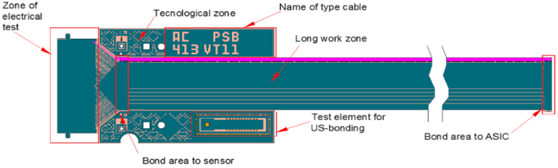
- FEE connected via micro-cable lines (64 lines/cable)

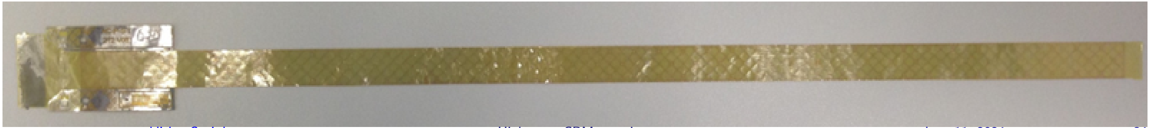


- 2×1024 ch./sensor: stack of 32 micro cables per module, 8 sub types
- Length from 160 mm to 495 mm



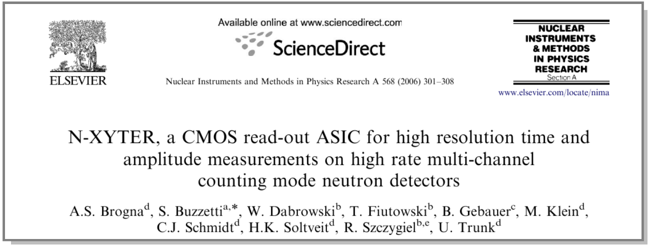
↗ Read-out lines are protected w/ shielding layers





nXYTER: ASIC that measures time and amplitude

- nXYTER was a dedicated ASIC for (ToF and Imaging) neutron detectors
  - one of applications: double-sided Silicon micro-strip detector (coupled to a Gadolinium neutron-converter layer)



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Nuclear Instruments and Methods in Physics Research A 568 (2006) 301–308

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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N-XYTER, a CMOS read-out ASIC for high resolution time and amplitude measurements on high rate multi-channel counting mode neutron detectors

A.S. Brogna[d], S. Buzzetti[a,*], W. Dabrowski[b], T. Fiutowski[b], B. Gebauer[c], M. Klein[d], C.J. Schmidt[d], H.K. Soltveit[d], R. Szczygiel[b,e], U. Trunk[d]

nXYTER: ASIC that measures time and amplitude

- nXYTER was a dedicated ASIC for (ToF and Imaging) neutron detectors
  - one of applications: double-sided Silicon micro-strip detector
    (coupled to a Gadolinium neutron-converter layer)
  - two paths after CSA: slow (amplitude) and fast (time)

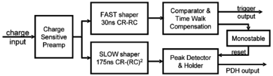


Fig. 1. Block diagram of a single channel of the realized ASIC.

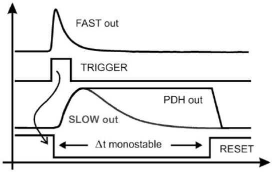
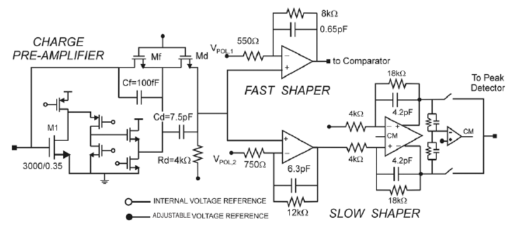


Fig. 2. Diagram illustrating the main signals inside the ASIC.



...YTER, a CMOS read-out ASIC for high resolution time and amplitude measurements on high rate multi-channel counting mode neutron detectors

...rogna[d], S. Buzzetti[a,*], W. Dabrowski[b], T. Fiutowski[b], B. Gebauer[c], M. Klein[d], C.J. Schmidt[d], H.K. Soltveit[d], R. Szczygiel[b,e], U. Trunk[d]

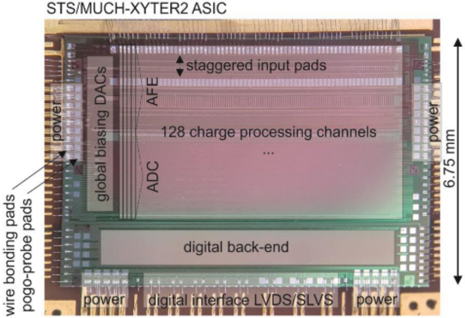
- Analogue memory, external ADC required

Latest Generation: STS-MUCH-XYTER v 2.2

Features of the ASIC:

- Low-power, self triggering AISC
- 128 channels + 2 test channels
- Time resolution $\lesssim 5\,\mathrm{ns}$
- Provides digitized hits with:
  - 5 bit energy resolution
  - 14 bit time stamp
- Linearity range up to $15\,\mathrm{fC}$ $(100\,\mathrm{fC})$
- **Flash ADC + digital buffer** integrated in ASIC

K. Kasinski *et al* Nucl.Instrum.Meth.A 908 (2018)



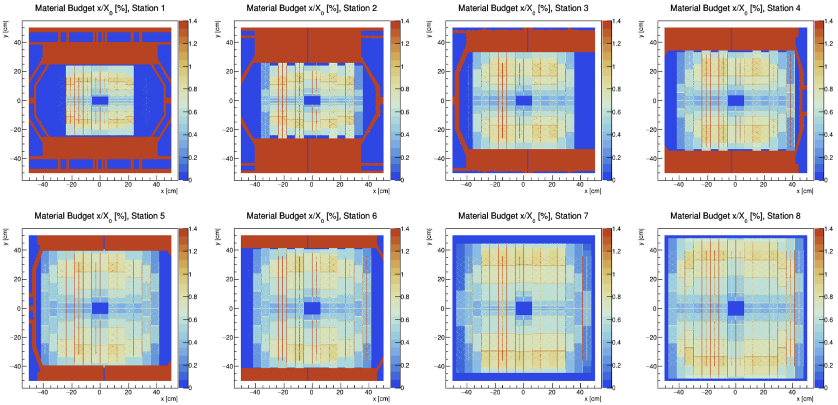
Current status:

- ASIC production yield 98.5%–99.0%, chip cable yield 96%
- **production:** ~ 4000 available for series module production
- 360 dies per wafer, 100 wafers produced

Simulation of the detector performance

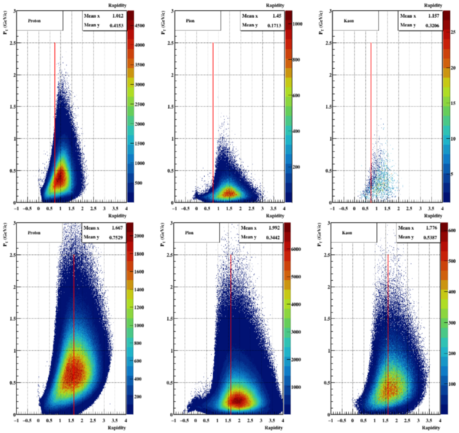
material budget

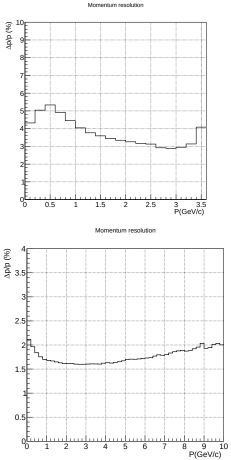
- Down to $0.3\%\, X_0$ per layer around the bending plane,
- No more than $1\%\, X_0$ at the periphery



Simulation of the detector performance

acceptance and momentum resolution

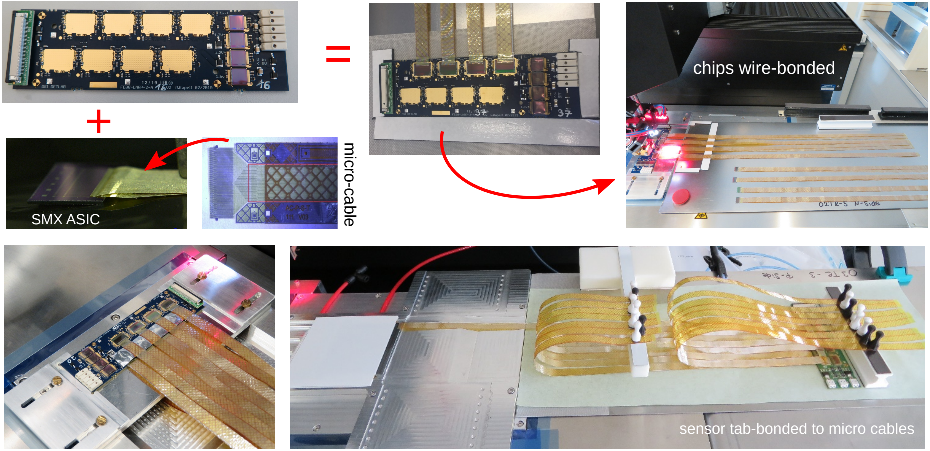




- Au target with $2\,\mathrm{GeV}/c$ Au beam (upper row), $12\,\mathrm{GeV}/c$ Au beam (bottom row)

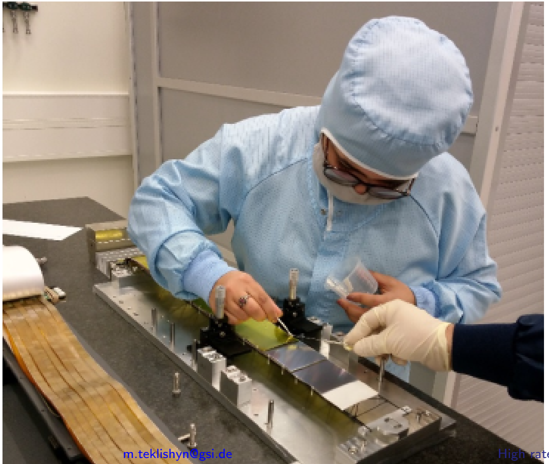
Module assembly

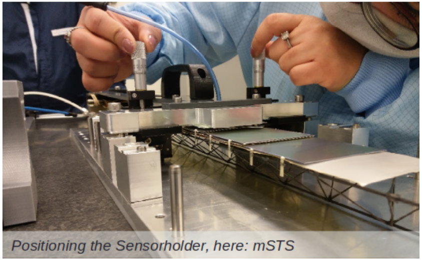
- STS detector modules are produced in the assembly centres in GSI and KIT
  - about 100 series modules already produced



Ladder assembly sequence

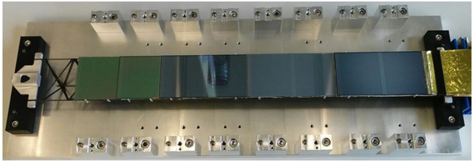
- From 8 to 10 detector modules installed on the light-weight carbon structures: ladders
- Sensors precisely positioned ($\lesssim 30\,\mu\mathrm{m}$) with jigs





Positioning the Sensorholder, here: mSTS

- Assembled ladders undergo metrology survey and functionality tests



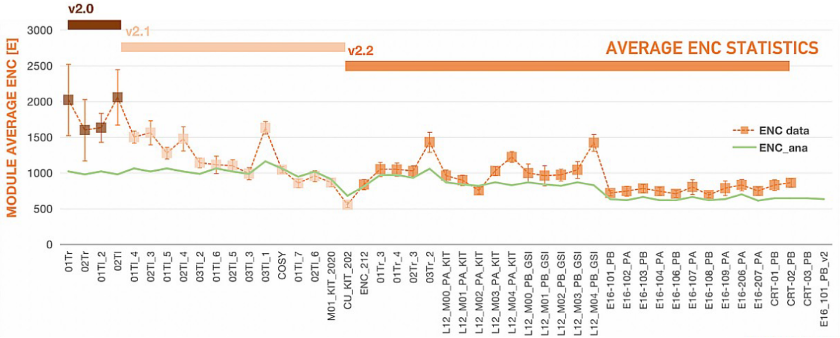
- After tests ladder is installed on c-frame

- Studies and experience are summarised in our paper:

Functional characterization of modules for the Silicon Tracking System of the CBM experiment

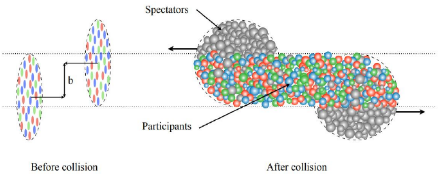
A. Rodríguez Rodríguez[a,*], O. Maragoto Rodríguez[a], J. Lehnert[a], A. Toia[a,b], M. Teklishyn[a,c], A. Lymanets[a], D. Rodríguez Garcés[a,b], J. M. Heuser[a], C. J. Schmidt[a]

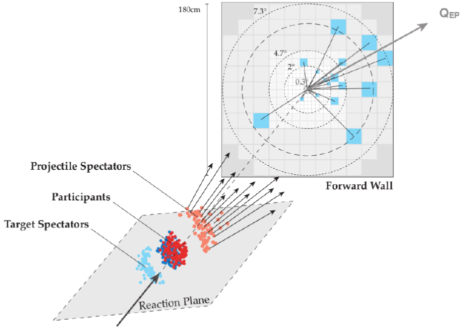
[a] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, Darmstadt, 64291, Germany
[b] Goethe Universität, Max-von-Laue-Str. 1, Frankfurt am Main, 60438, Germany
[c] Institute for Nuclear Research, Prospekt Nauky 47, Kyiv, 03680, Ukraine

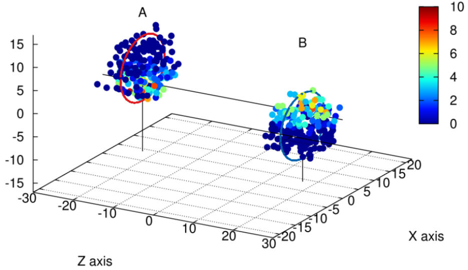


Reaction plane and centrality

- Determination of the impact parameter value and angle
  - track multiplicity (centrality related; bias for fluctuation studies)
  - spectator fragments distribution in forward detector

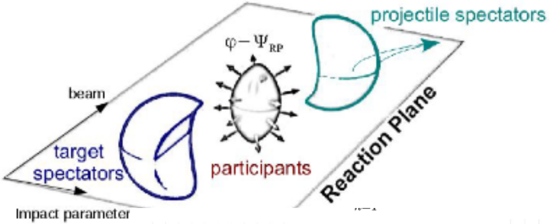






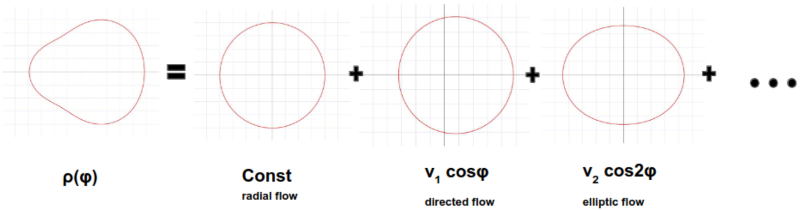
Anisotropic flow

Spatial anisotropy of the energy density of the matter produced in HIC converts to **momentum anisotropy** of produced particles due to interaction between them



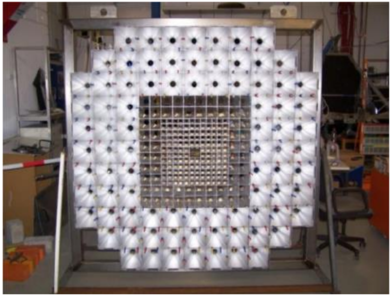
$$\rho(\varphi, p_T, y) \propto$$
$$1 + 2\sum_{n=1}^{\infty} v_n(p_T, y)\cos(n(\varphi - \Psi_{RP}))$$

$$v_n = \langle \cos[n(\varphi - \Psi_{RP})]\rangle$$



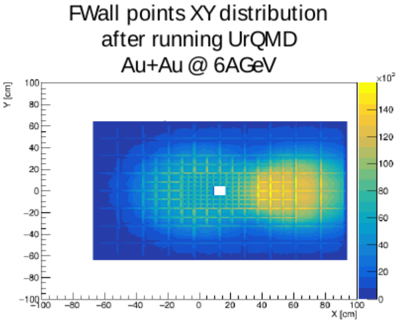
Forward WALL

CBM spectator calorimeter

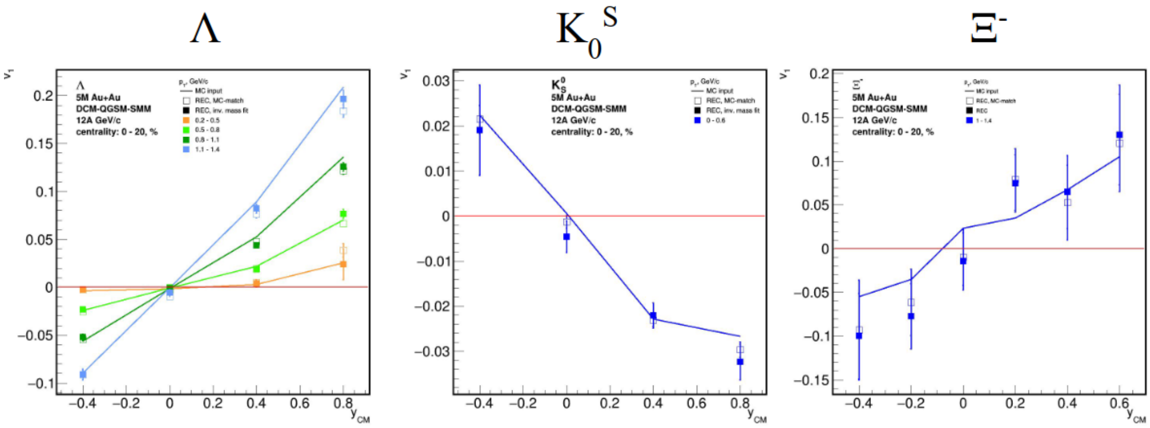


FWALL DESIGN

- FWALL size is $160\,\mathrm{cm} \times 128\,\mathrm{cm} \times 10\,\mathrm{cm}$
- FWALL contains 220 modules
- One quadrant:
  - Number of **SMALL** modules: $6 \times 4 - 4$ (hole)
  - Number of **MEDIUM** modules: 3×2
  - Number of **LARGE** modules: 2×2
- Scintillator hodoscope (depth $\simeq 2.5\,\mathrm{cm}$)
  - 140 small cells ($4 \times 4\,\mathrm{cm}^2$)
  - 64 middle cells ($8 \times 8\,\mathrm{cm}^2$)
  - 84 large cells ($16 \times 16\,\mathrm{cm}^2$)

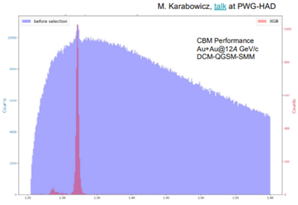


Directed flow (v_1) of strange hadrons

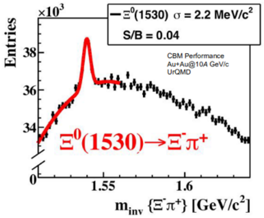


- Signal's extraction using invariant mass fit method gives results consistent with MC-extraction
- Flow coefficient calculated in data-driven mode reproduces MC-input within statistical errors

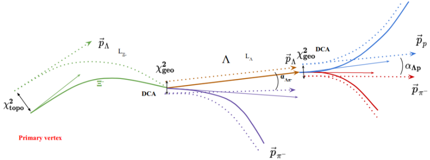
Reconstruction of complex topologies



invariant mass of Ξ⁻ candidates



M. Zyzak, PhD thesis @ UFra, 2016

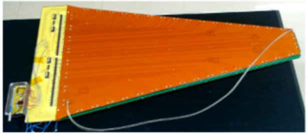


- Global tracking covering extended decays (MVS/STS ⟶ MUCH/TRD ⟶ ToF)
- Particle identification: electrons (RICH, TRD), hadrons (ToF), muons (MUCH)

Muon Chambers

- MuCh detector: muon identification and global (muon) tracking
- Two technologies: GEM and RPC are being involved

  - 4 stations and 4 + 1 absorbers
  - GEM detector technology (3 mm Ar/CO_2)
  - Graphite absorber (magnet), followed by Fe
  - Geometrical acceptance: 5.7 – 25 degree

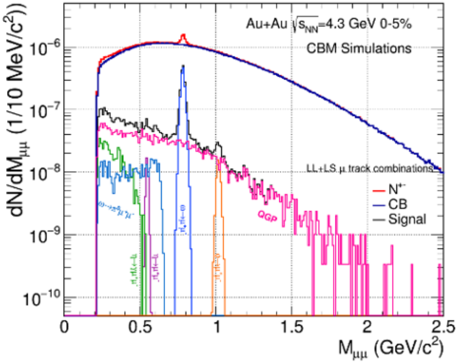


Real-size (80 x 40 cm^2) GEM detector module

Detector testing at CERN-SPS, November 2016:

  - Large-size chambers succesfully operated in fixed-target testbeam (Pb+Pb)

- Reconstruction of di-muon cocktail: 8 *A*GeV Au+Au
- Track selection: associated hits in STS and MuCh, track χ^2 at STS/MuCh/prim. vertex, TOF mass cut



Čerenkov detector for pion/electron separation

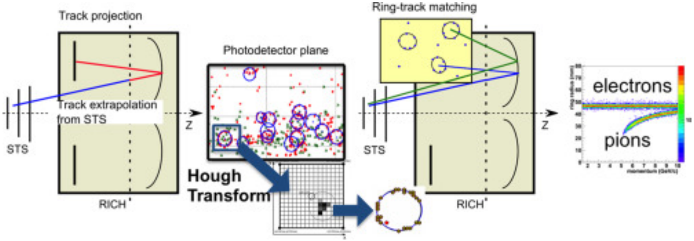
Aim: clean electron identification for momenta below $8\,\mathrm{GeV/c}$

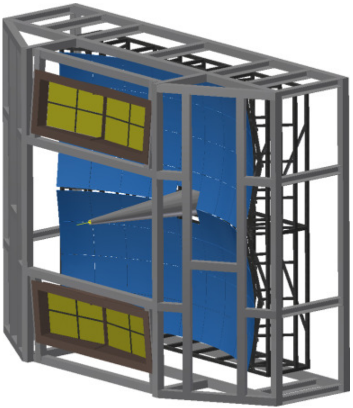
Photodetector (2.4 m^2, 55k Ch.)

- photomultipliers (MAPMT: H12700 series)
- fast self-triggered readout

mirror (11.8 m^2)

- glass mirror: R=3m, $\leq 6\,\mathrm{mm}$ thickness, Al+MgF_2 coverage
- CO_2: $\gamma_{th} = 33$, $p_{th} = 4.65\,\mathrm{GeV/c}$
- $\Rightarrow$ Photons with $\lambda \geq 180\,(200)\,\mathrm{nm}$

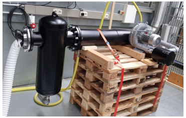




Čerenkov detector prototyping

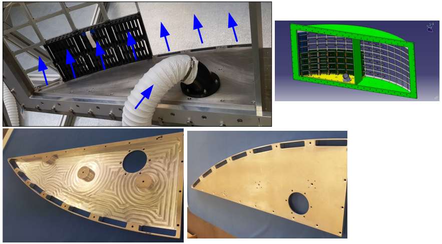
- Full-scale RICH camera demonstrator: test of the forced-convection cooling of electronics

Prototype photon camera for CBM RICH



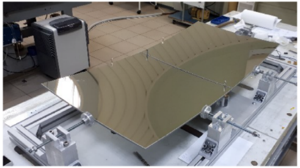
Prototype cooling system
blower + heat exchanger

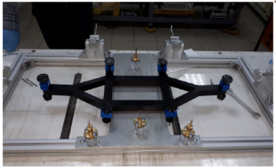
heat exchanger : sufficient for full RICH
blower : sufficient for one camera



Cooling air distribution via "distributor box" into 7 outlets guiding air to the module columns
–> how (un)equal is the air flow out of the 7 outlets ???

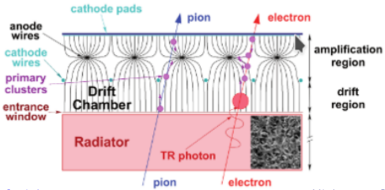
- RICH mirrors (left) and their mechanical support prototype (right)

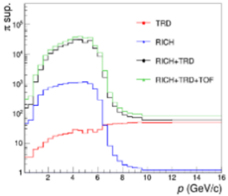


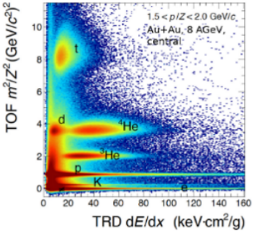


Transition Radiation detector

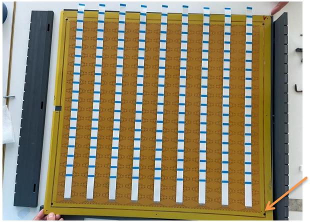
- PID with the transition radiation emitted by relativistic light particles
- Multi-wire proportional chambers (12 mm Xe/CO_2), fast design, PE foam foil radiator
- Read-out: mirror charge on cathode-pads
- Electron detection due to absorption of TR photons additional to particle energy loss
- Pion suppression by four TRD layers
- Separation of light nuclei, e.g. d $\rightarrow {}^4$He (reconstruct: ^{5}He $\rightarrow {}^4$He + p + π^- // ^{6}He)



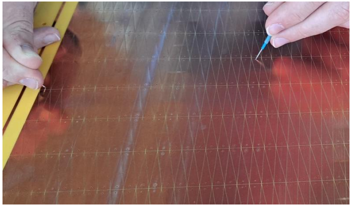




TRD-2D prototype assembling

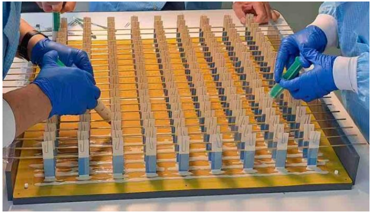


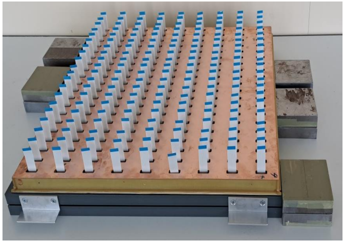
Alignment holes



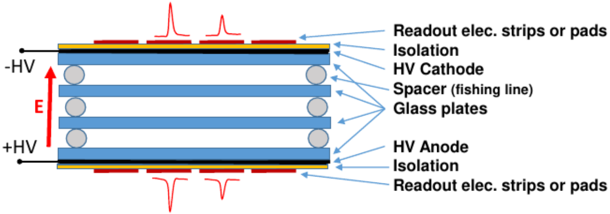
The back plane assembled

Flat cables positioning before mounting on the back plane

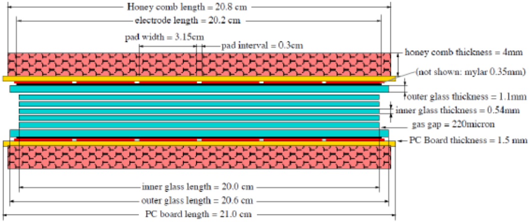




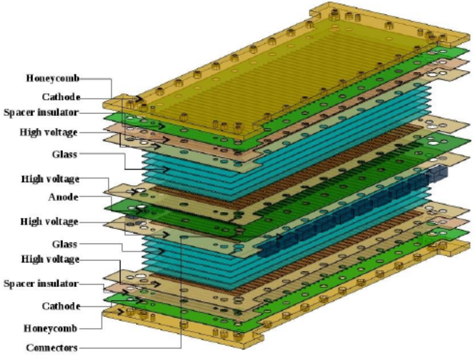
Multi-gap RPC (MRPC)



Single stack MRPC, STAR (2004) –first generation

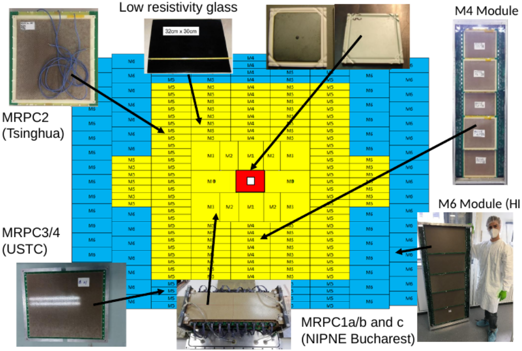


Double stack high rate MRPC, CBM (2020) - second generation



Time of Flight detector

- Detector layout optimised for different occupancy regions
- Full size counter with close to final design for all regions build and tested
- M4 and M6 full size modules constructed and installed at mCBM



Materials:

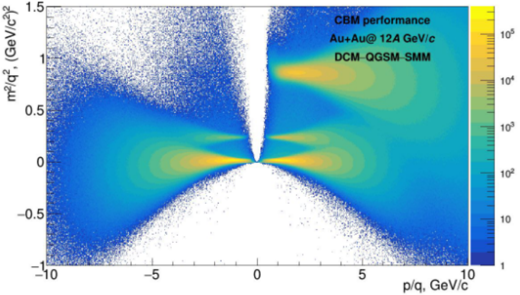
- thin float glass, $\rho\, 10^{12}\,\Omega\,\mathrm{cm}$
- low resistivity glass, $\rho\, 10^{10}\,\Omega\,\mathrm{cm}$
- ceramic, $\rho\, 10^{9}\,\Omega\,\mathrm{cm}$

Statistics:

- 230 + 20 modules
- 1400 MRPCs
- 90000 channels

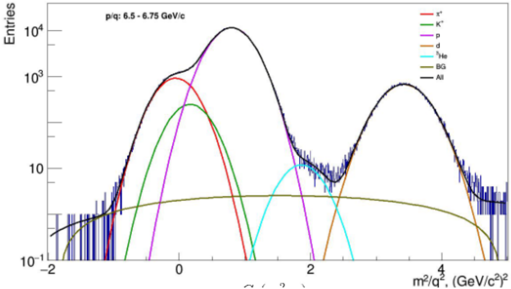
Bayesian identification using TOF

$$\frac{m^2}{q^2} = \frac{1}{c^2}\frac{p^2}{q^2}\left(\frac{c^2t^2}{L^2} - 1\right)$$



Particles with same m/q (e.g. d and He-4) are indistinguishable

PhD thesis O. Lubynets

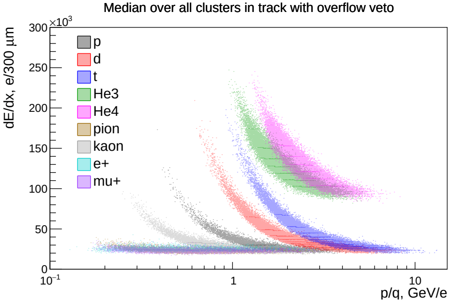


$$P_j(m^2,p) = \frac{G_j(m^2,p)}{\sum_{i=\pi,p,K} G_i(m^2,p) + BG(m^2,p)}$$

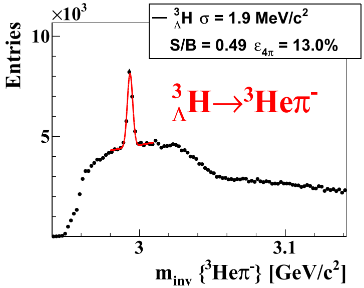
- use as weight in yield calculation
- the highest value
- value over threshold (purity cut)

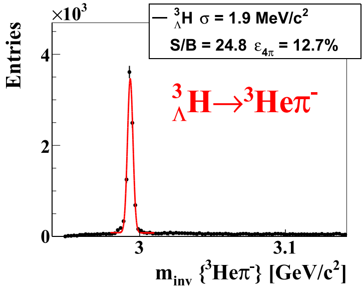
Simulation of PID with STS

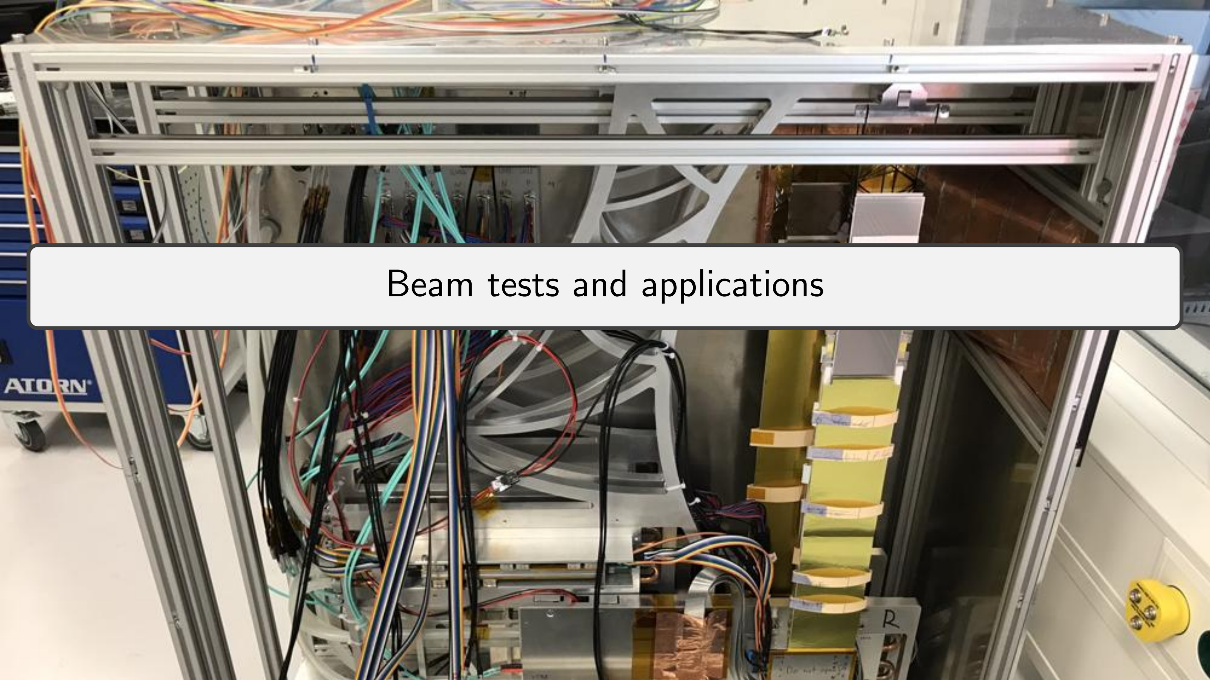
$\Delta E/\Delta x$ information for hypernuclei



- The strongest discrimination expected for He/H
- Natural implementation in hypernucleus analysis
  - TOF PID only, significant background (left)
  - TOF + STS PID combined, almost zero background (right)
    - single criteria of $\Delta E_{\text{median}} > 75\,\text{ke}$ for ^3He, $\forall p$



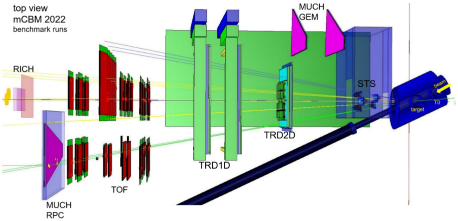


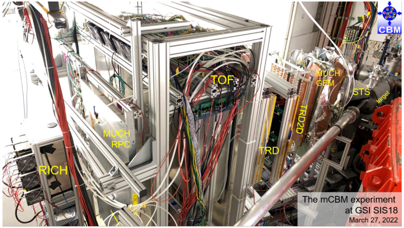


Beam tests and applications

mCBM experiment

- mCBM experiment as a pathfinder for CBM
  - ultimate test of the detector prototypes
  - test of the read-out chain and data acquisition





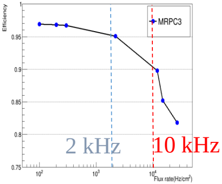
- **mCBM setup** at SIS18 features detector prototypes of key systems
- Installed @SIS18 accelerator at GSI
  - beam campaigns in 2018–2022
  - detector evaluation and phys. analysis

MRPC3/4 performance at mCBM

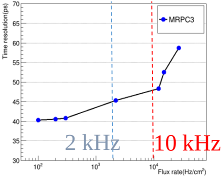
- Prototype tests in mTOF
- mCBM@SIS18 2021 beam time

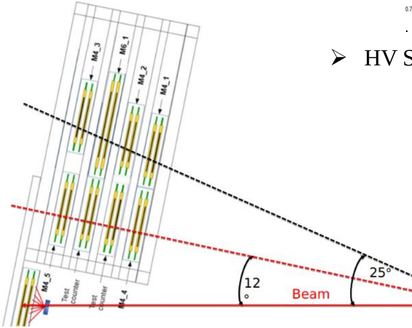
Gas mixture: 97.5%Freon + 2.5%SF_6

Efficiency



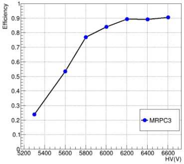
Time resolution



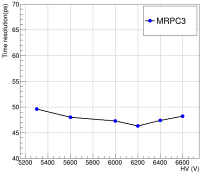


- HV Scan @ 10kHz/cm²

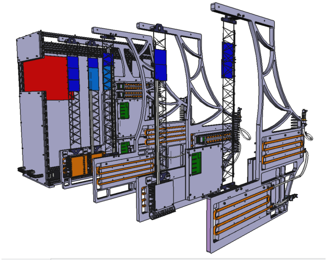
Efficiency

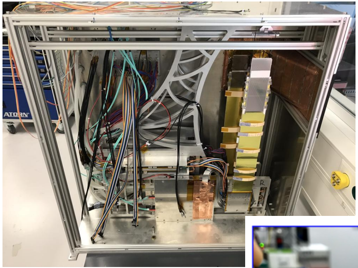


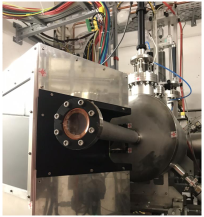
Time resolution



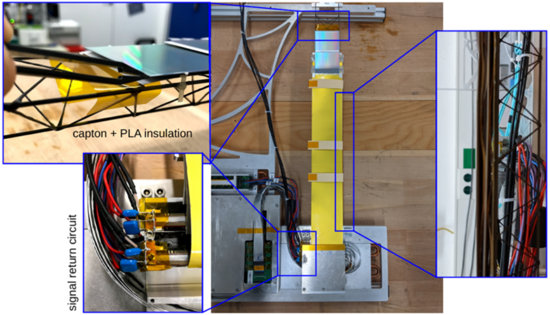
mSTS: functional full-scale detector prototype





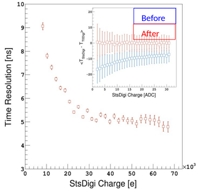


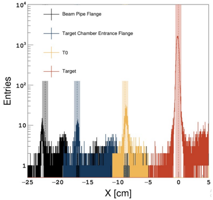
- Two tracking stations (layers) $12 \times 12\,\mathrm{cm}^2$ and $18 \times 18\,\mathrm{cm}^2$ arranged by 4 units
- Ultimate test of the detector performance **in the fully integrated system**
- Commissioning of the **assembling and testing procedures** to be used in series production
- Hit/track reconstruction performance with the **heavy ions in mCBM@SIS18 (GSI, Darmstadt)**



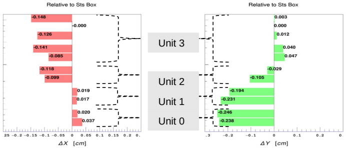
mSTS: recent beam-test highlights

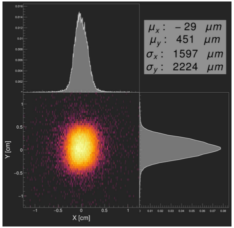
Dario A. Ramirez Zaldivar at VERTEX 2023



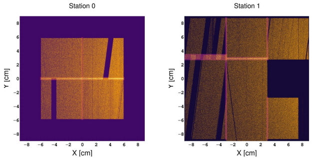


Sensor alignment translations are consistent with the mechanical assembly!

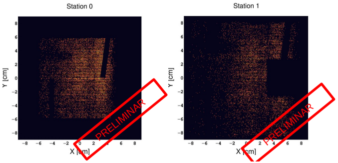




MC HRE >99.98%



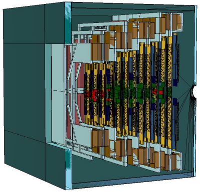
mCBM HRE >96.88%
Excluding inactive areas

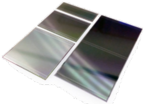


- Testing the free-streaming data acquisition system; data transport to a high-performance computer farm
- Online track and event reconstruction as well as event selection algorithms

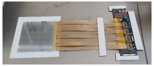
STS goes to Japan: synergy with E16 experiment

CBM-STS





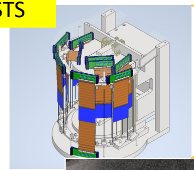
Silicon Sensors (Hamamatsu)

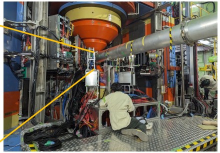


Sensor, cables, and Front-end electronics

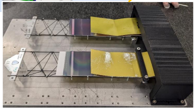
Sent to Japan for performance check

E16-STS

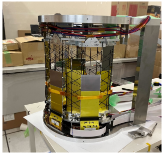




Spectrometer



Sensor, ladder, cable



E16-STS

CBM-STS is in the construction phase

Construction and operation methods will be improved by feedbacks from Japan

- Knowledge of constructions and operations and performance of total system are useful
- Experienced PD and student from KEK will join the CBM-STS construction

Feedback

E16-STS is installed and will be tested in the next year

Performance will be evaluated in high-rate counting situation

- 10MHz interaction rate

K. Ozawa @ 42th CBM Collaboration Meeting, September 28 2023

Conclusions and outlook

- CBM is a unique tool for detailed, high-statistics studies of
  - (differential) yields of multi-strange particles and hypernuclei
  - higher-order fluctuations, flows and correlations
  - detailed di-lepton spectra
- Self-triggering free-streaming detector read out
- Light-weight, radiation tolerant detectors
  - mCBM: a pathfinder for the final setup
  - detectors are being produced
- CBM installation (and individual system commissioning) until end of 2027
- First beam at 2028